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Kennedy et al.

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(54) **COMPOSITE BLADE ROOT-END DRILL-THROUGH LUG AND ATTACHMENT METHOD**

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B64C 27/48 (2006.01)

(52) **U.S. Cl.**
USPC .... **416/210 R**; 416/209

(58) **Field of Classification Search**
USPC .... 403/150, 151, 154; 416/205, 206, 416/207, 209, 201 A, 210 R, 210 A, 239
See application file for complete search history.

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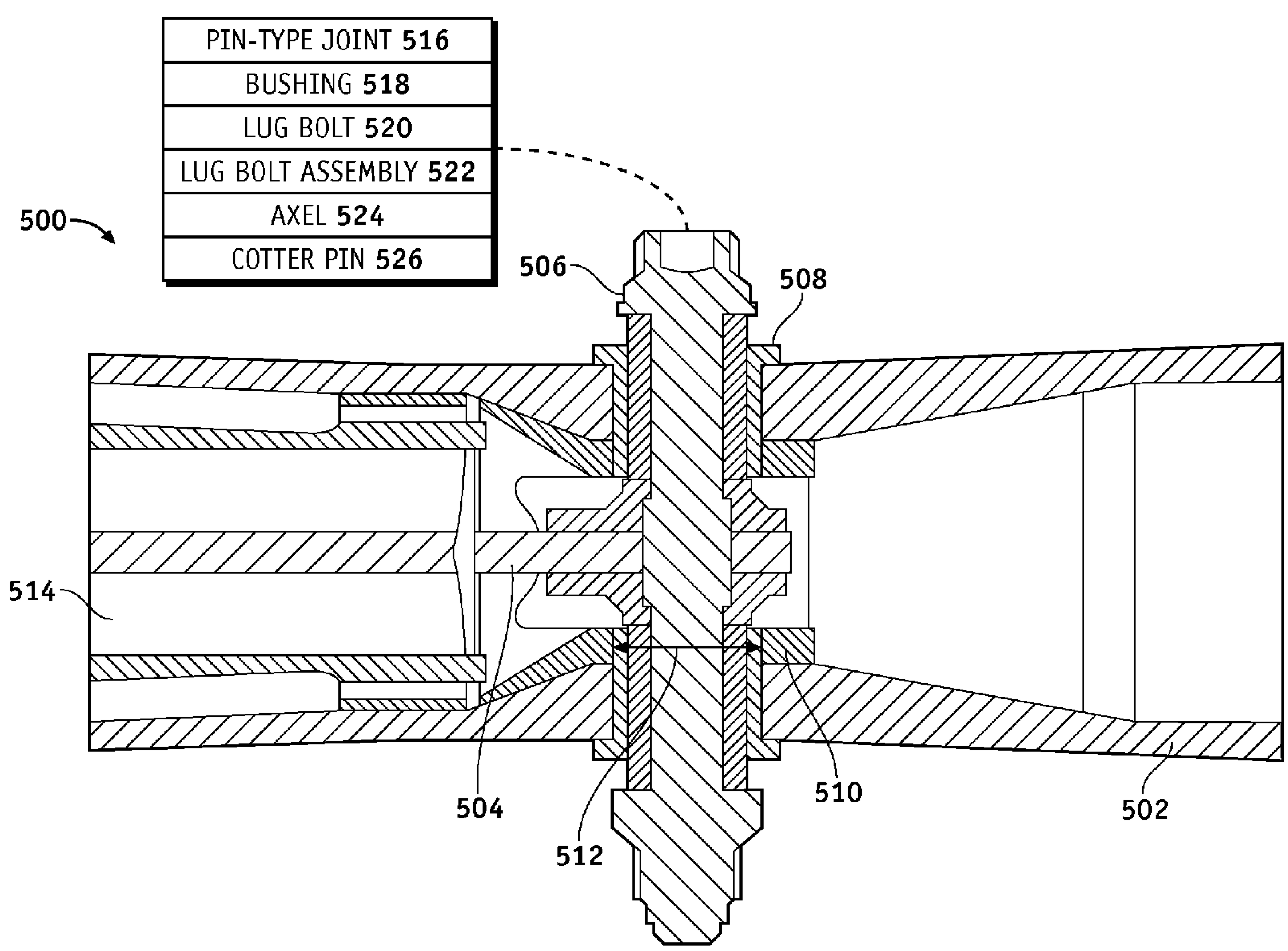
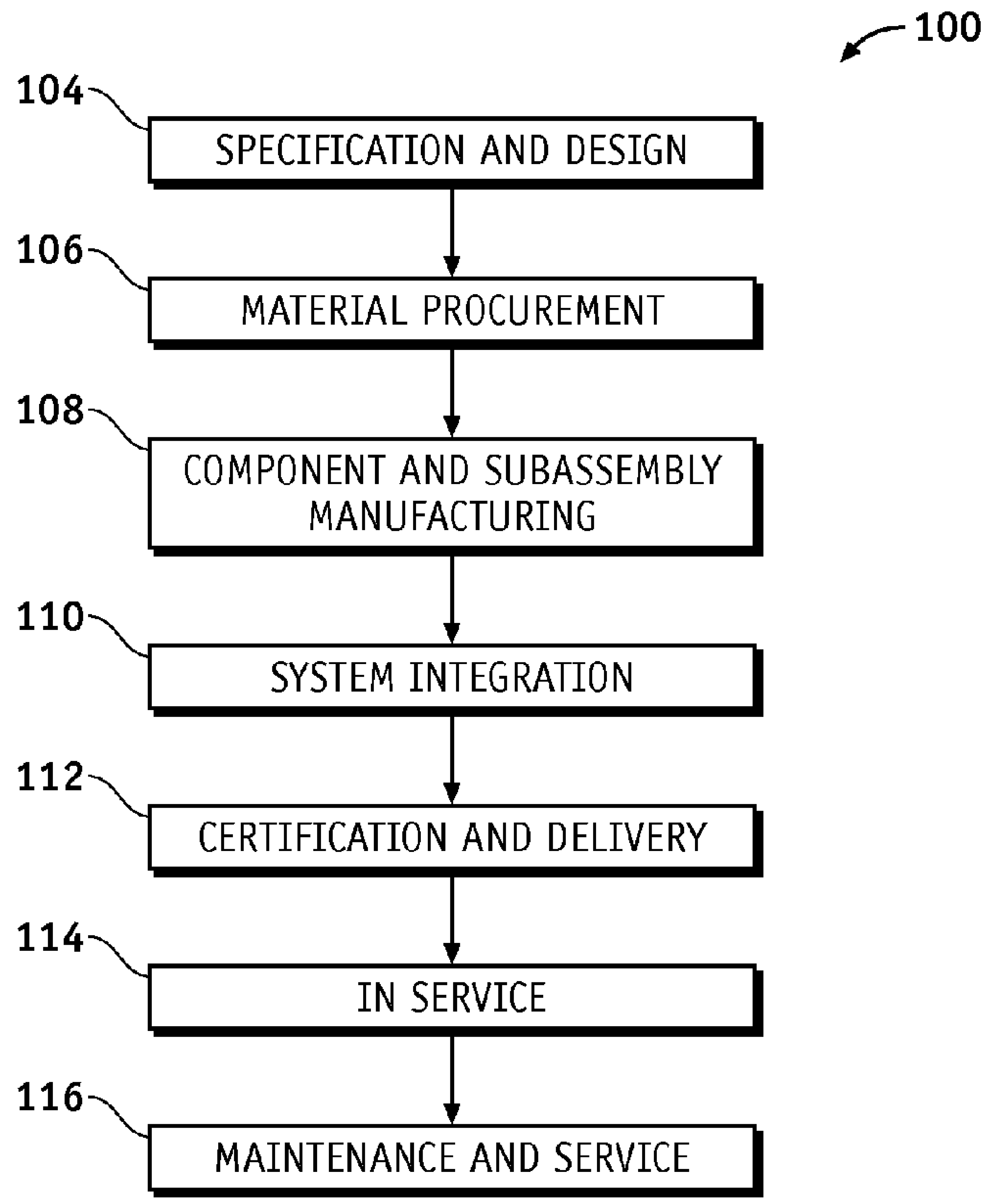
(57) **ABSTRACT**

A method for reducing bearing stress in a composite structure is disclosed. A composite structure comprises at least one coupling hole for coupling to the composite structure, and at least one bushing structure is coupled to the at least one coupling hole. A metal bushing retainer structure is coupled to the at least one bushing structure and the composite structure.

20 Claims, 9 Drawing Sheets




100
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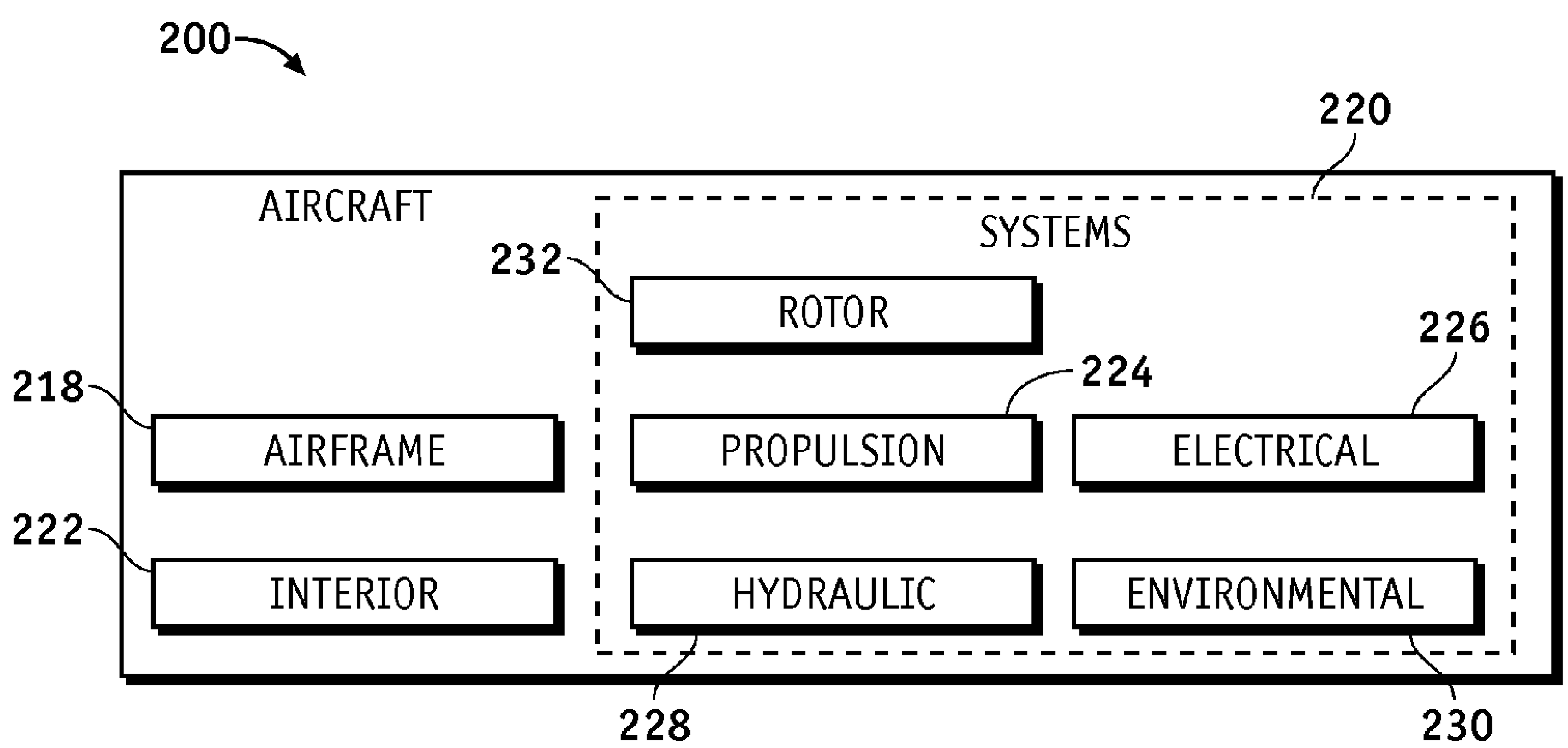
SPECIFICATION AND DESIGN
106
MATERIAL PROCUREMENT
108
COMPONENT AND SUBASSEMBLY MANUFACTURING
110
SYSTEM INTEGRATION
112
CERTIFICATION AND DELIVERY
114
IN SERVICE
116
MAINTENANCE AND SERVICE

FIG. 1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SYSTEMS
232
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ENVIRONMENTAL
228
230

FIG. 2

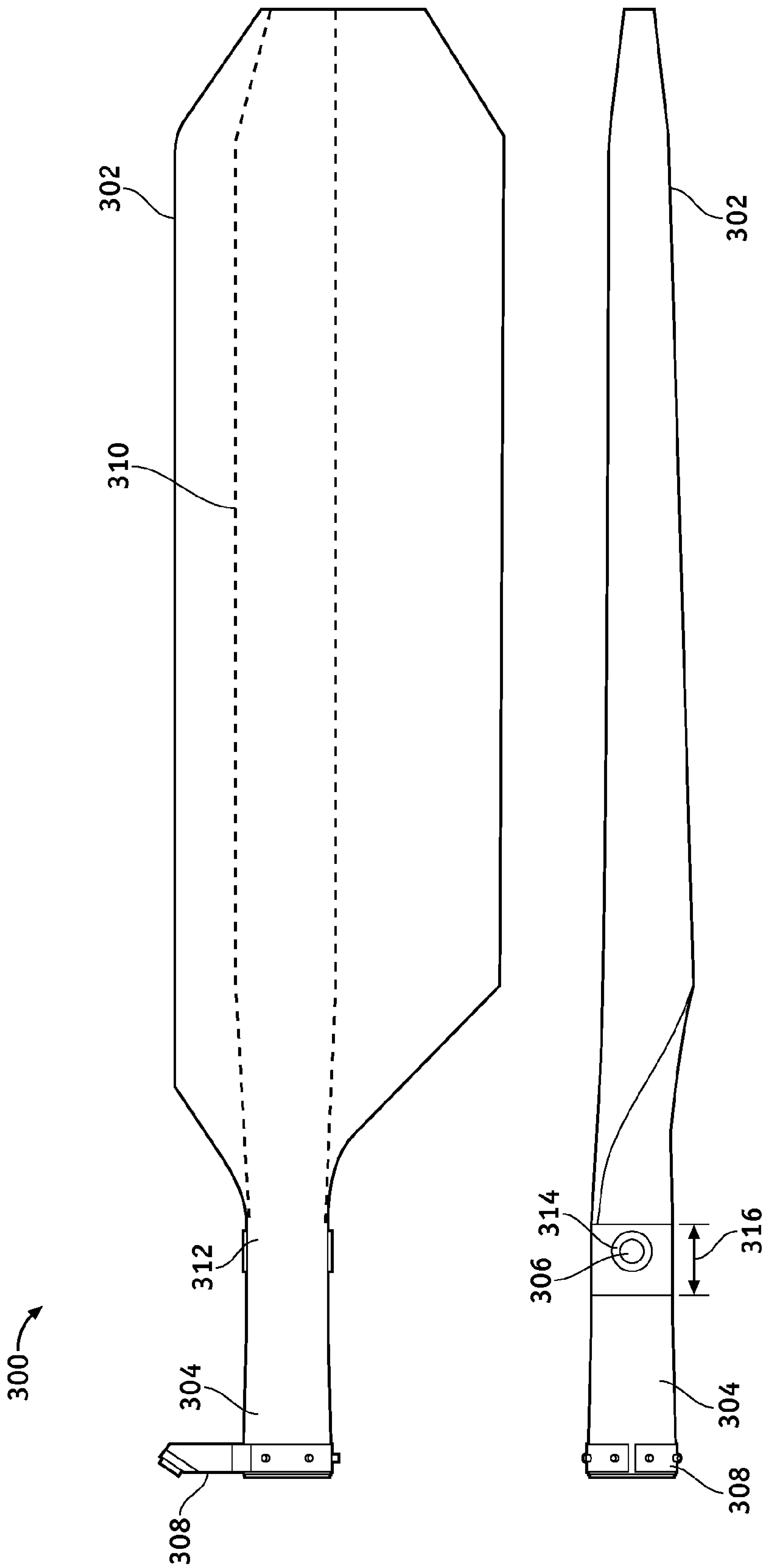
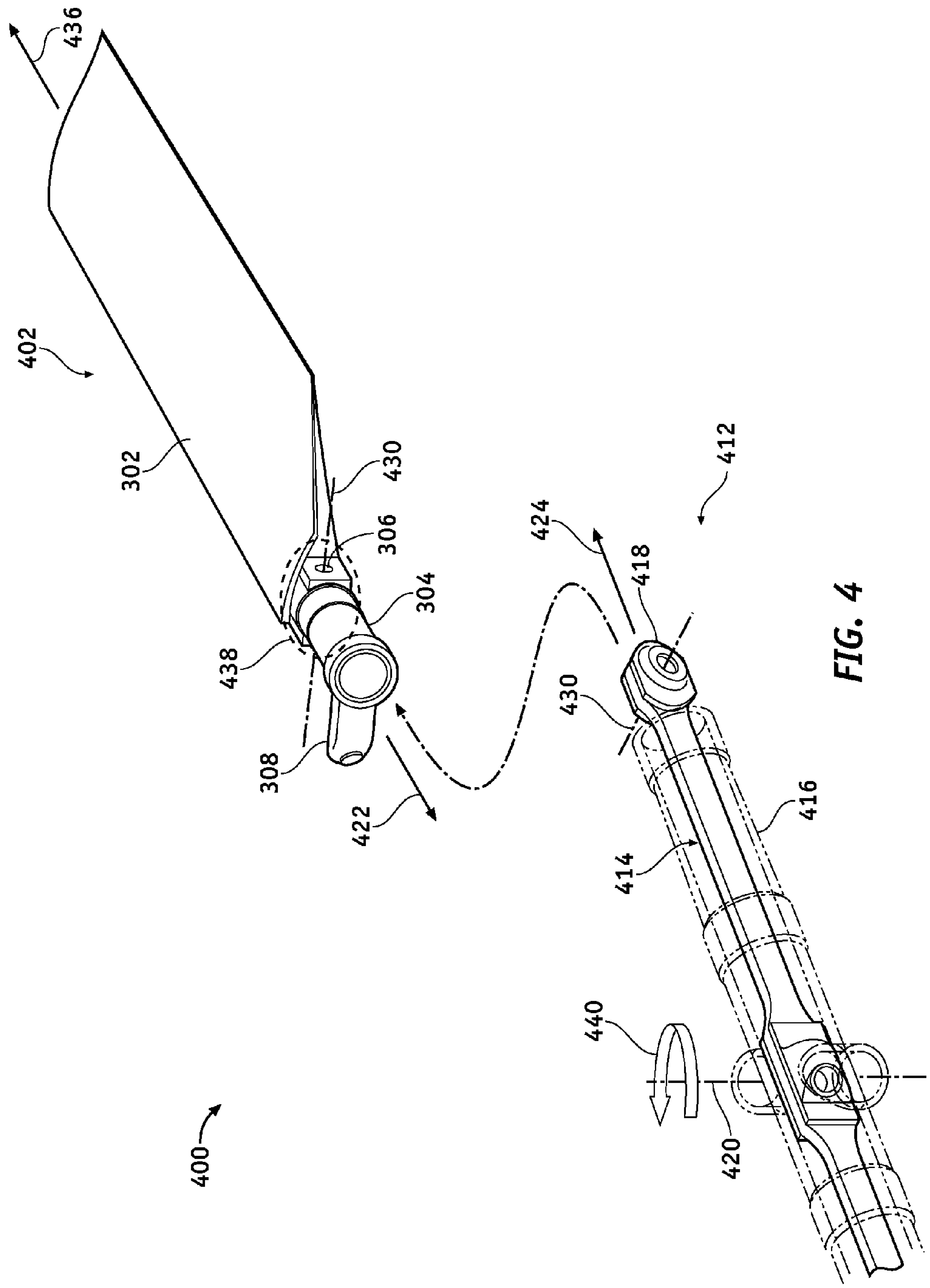


FIG. 3


436
402
302
430
306
304
438
308
422
424
418
412
430
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414
440
420
400

FIG. 4

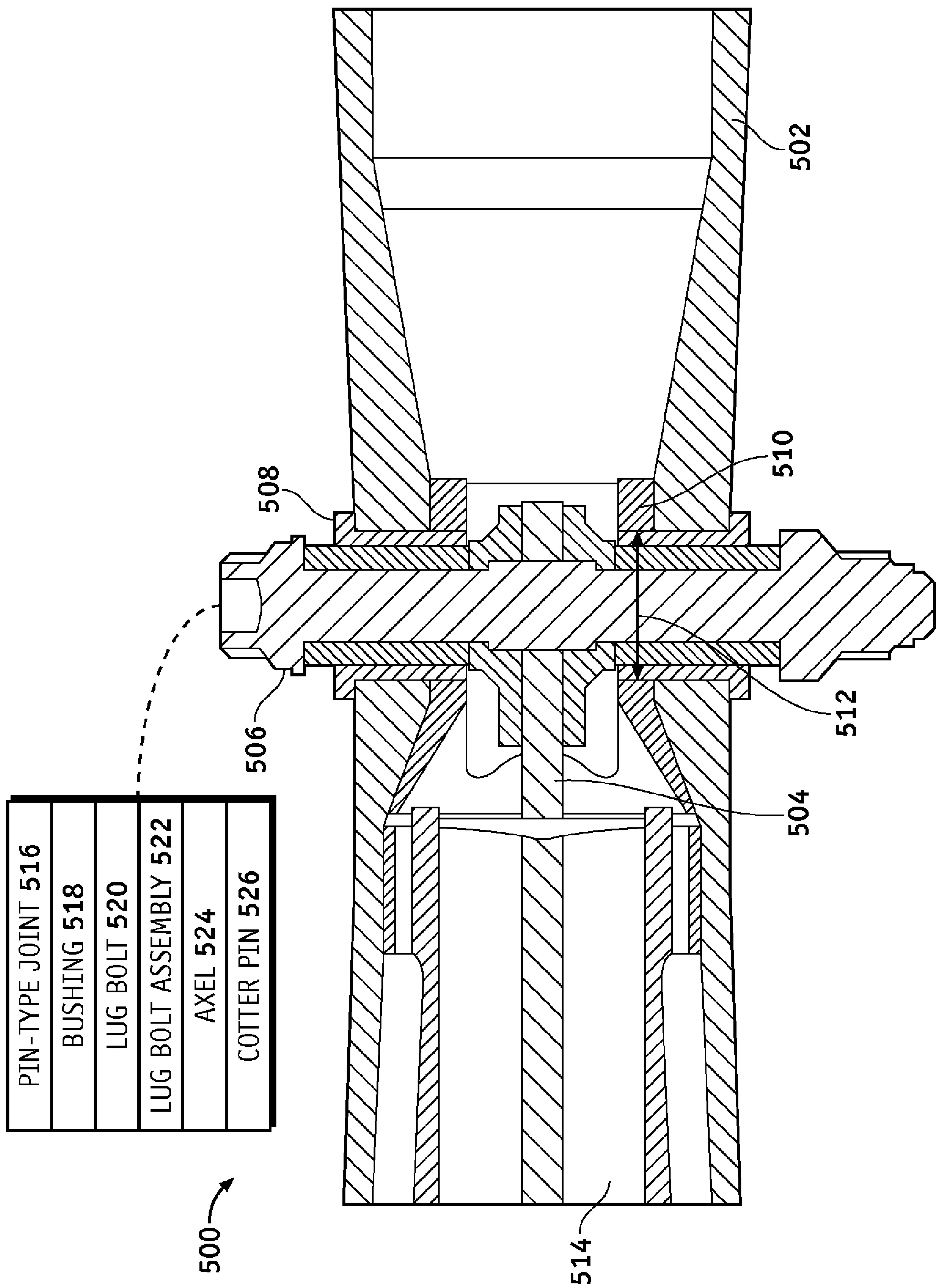

502
510
508
512
506
504
514
500
PIN-TYPE JOINT 516
BUSHING 518
LUG BOLT 520
LUG BOLT ASSEMBLY 522
AXEL 524
COTTER PIN 526

FIG. 5

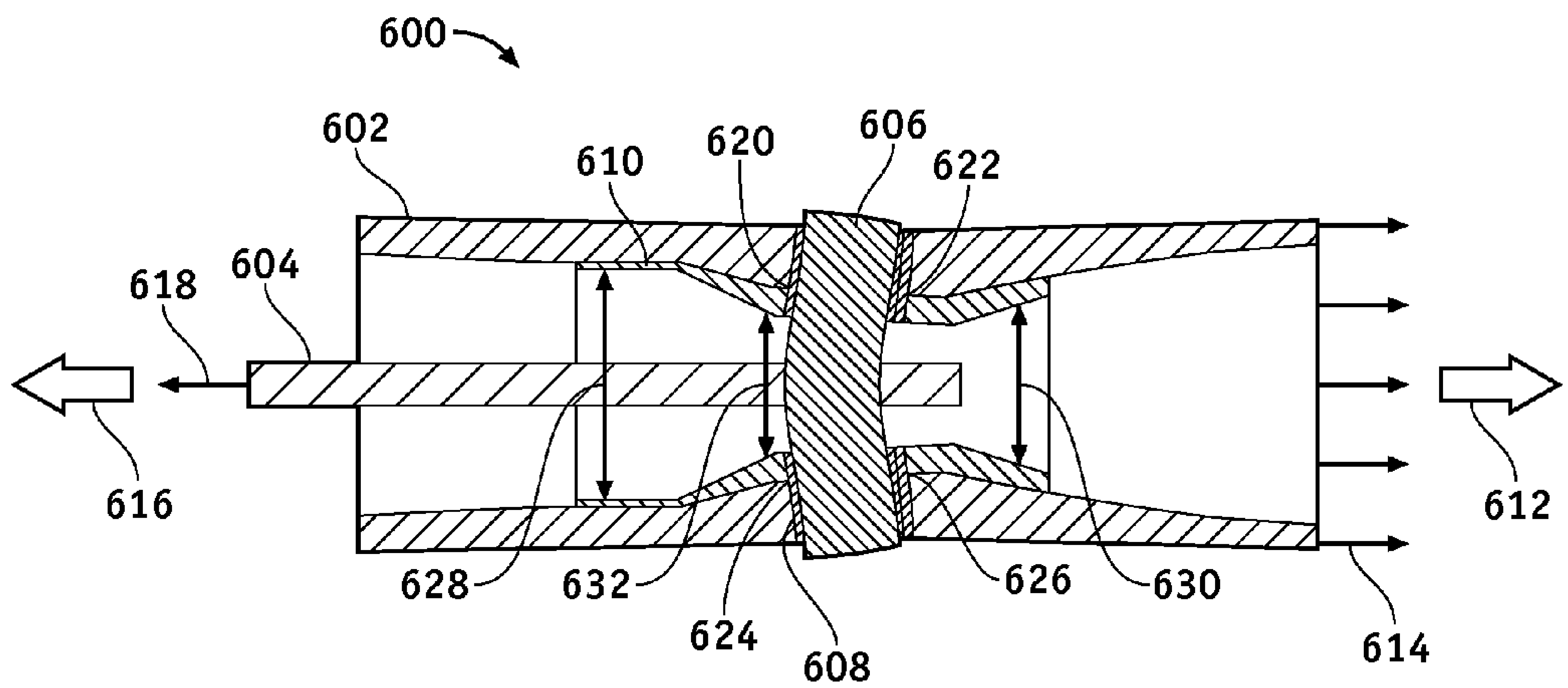
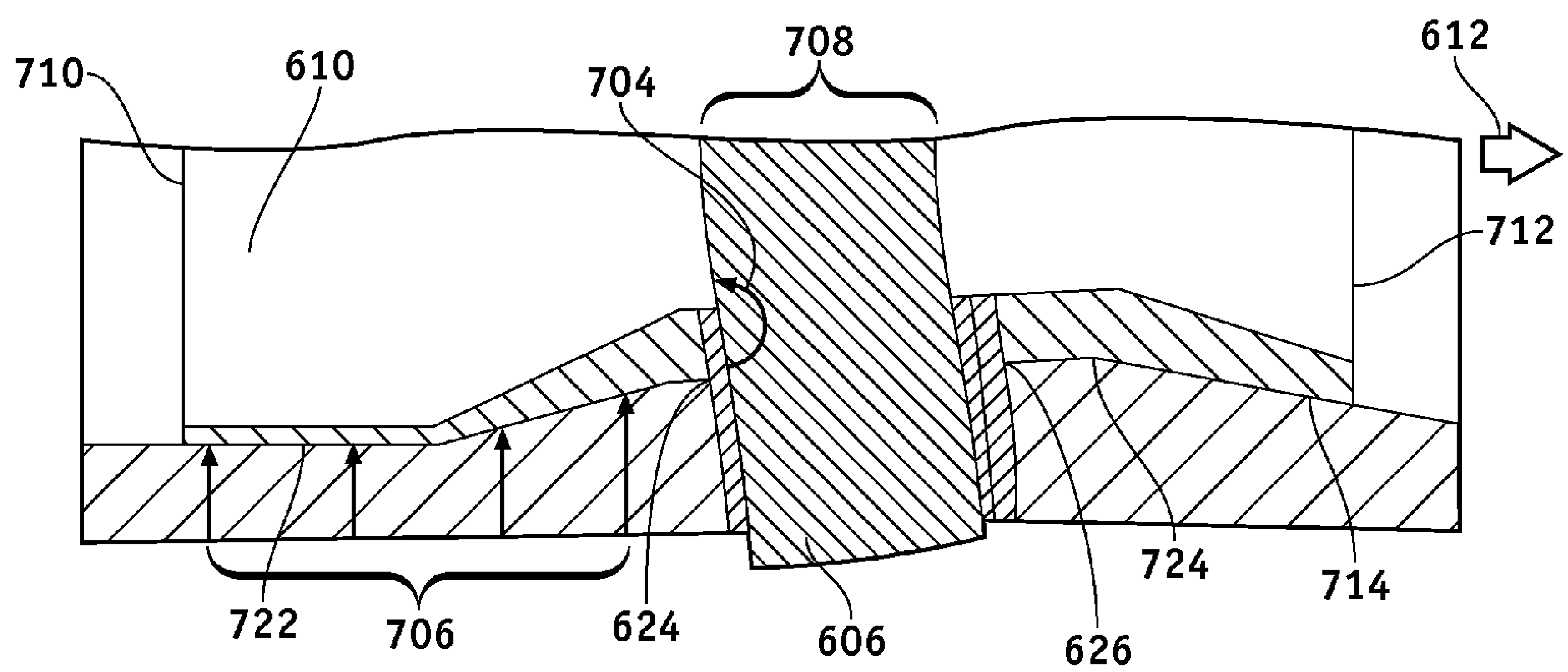

600
602
610
620
606
622
604
618
616
612
628
632
624
608
626
630
614

FIG. 6


710
610
704
708
612
712
722
706
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606
626
724
714

FIG. 7

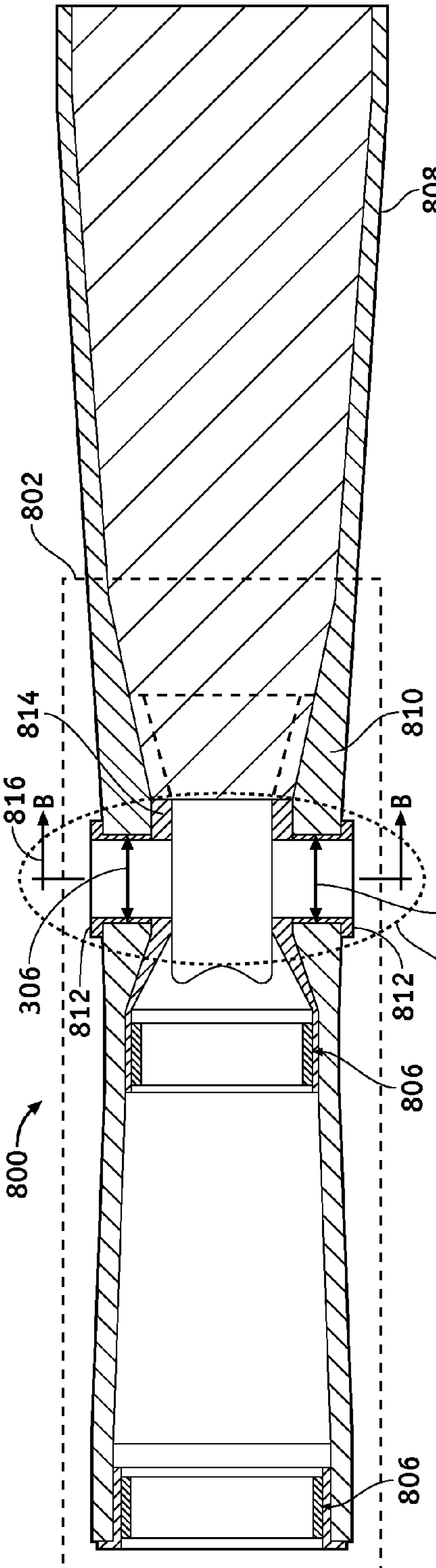

FIG. 8

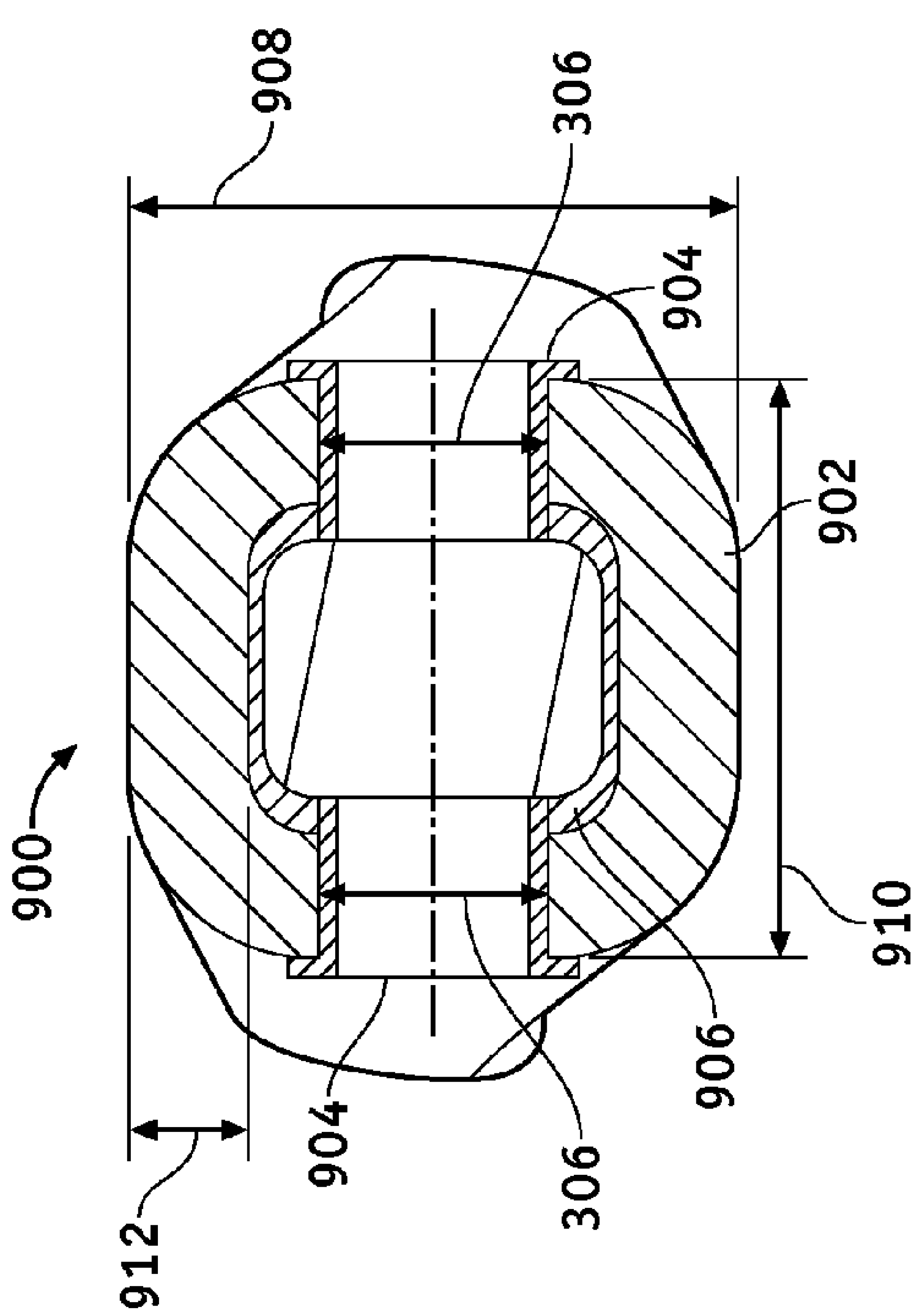

FIG. 9

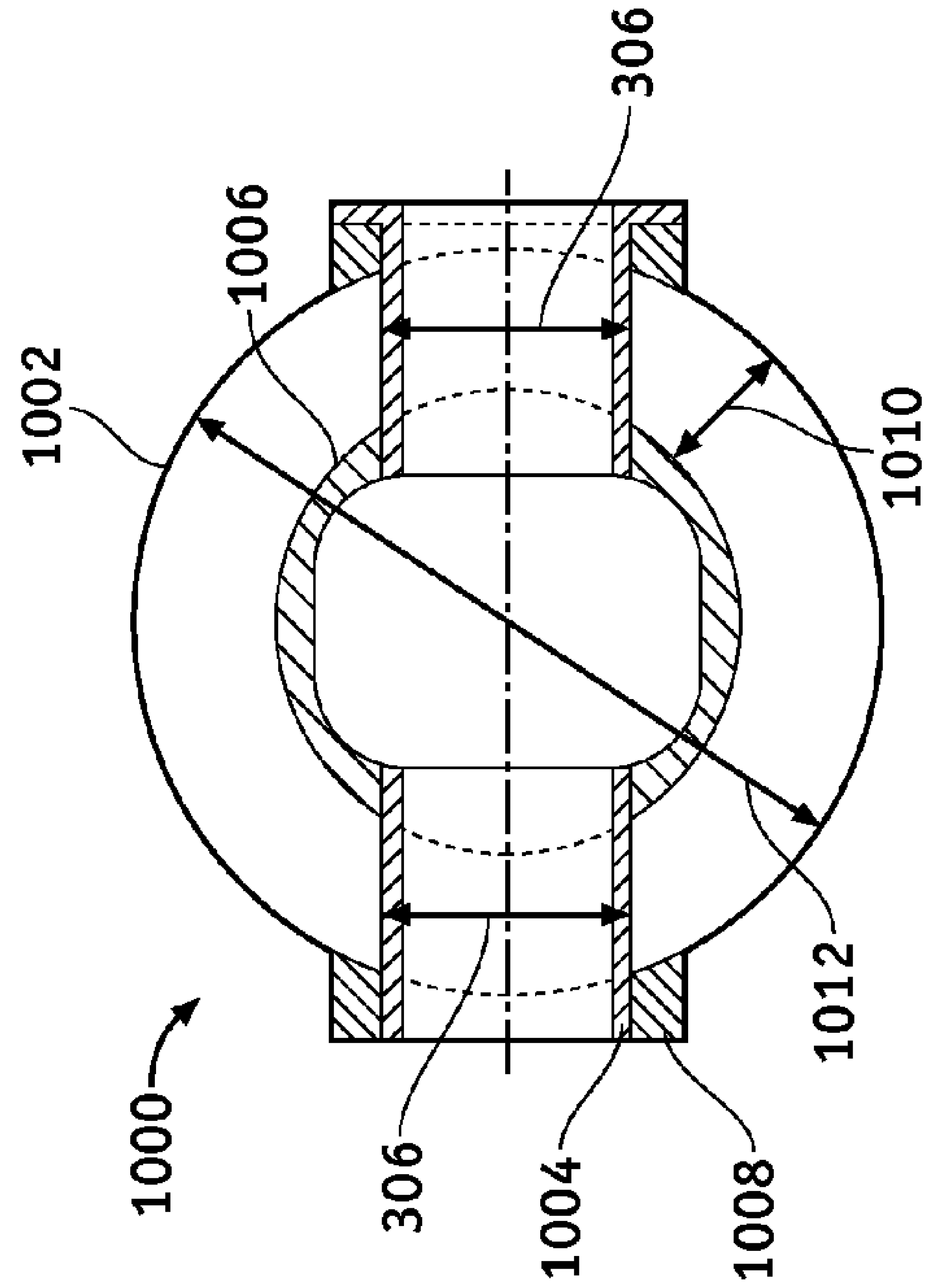

FIG. 10

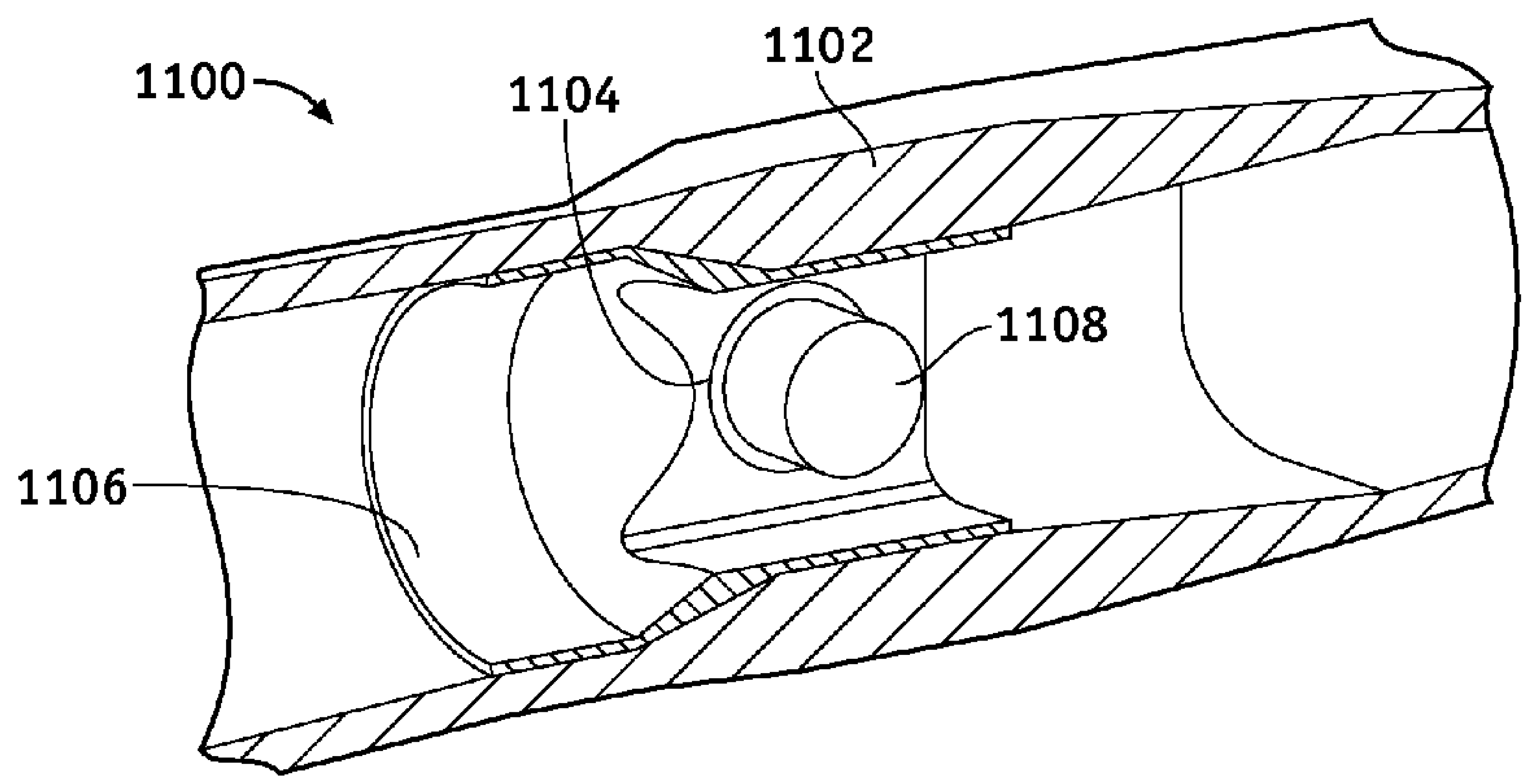

FIG. 11

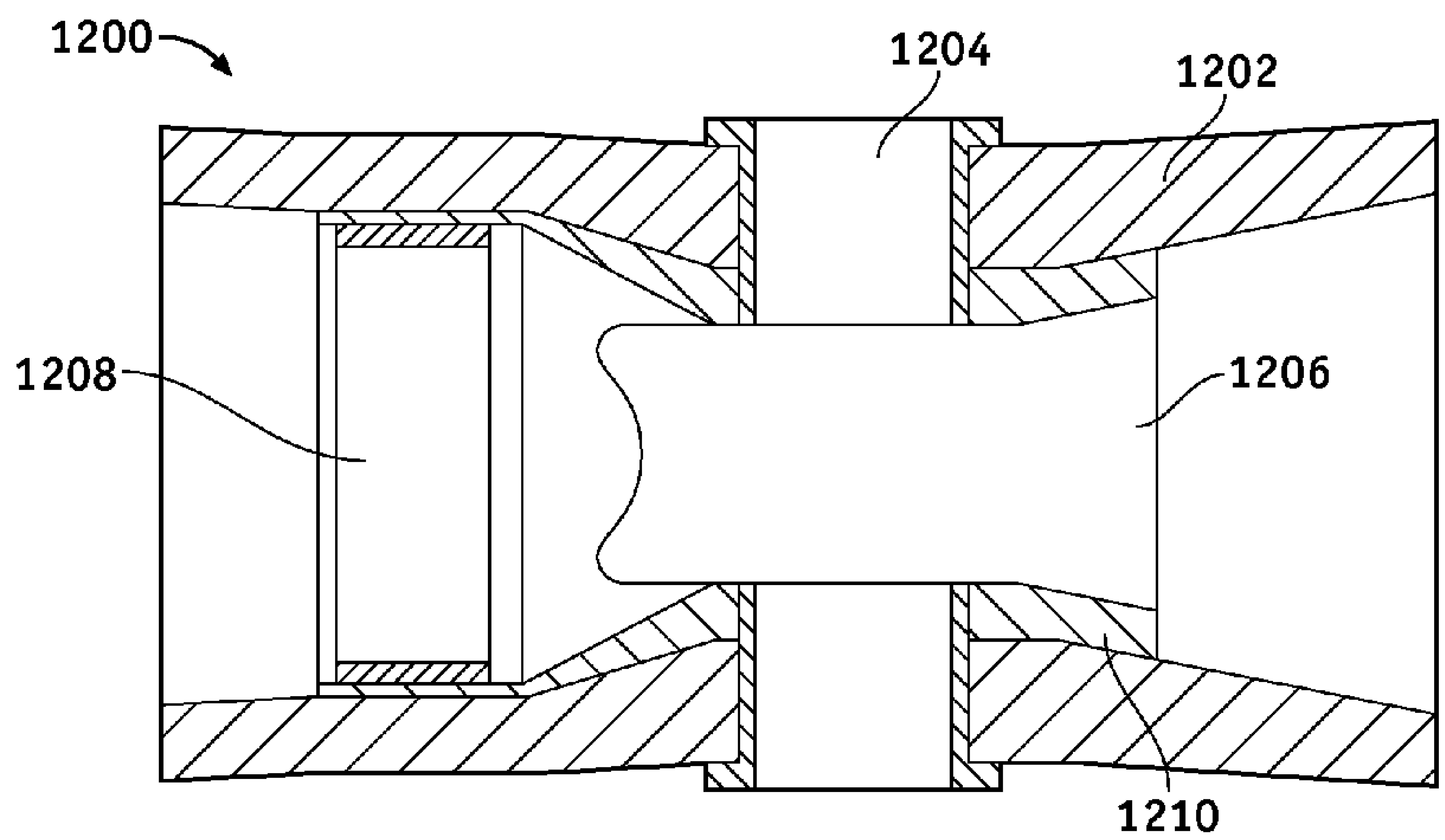

FIG. 12

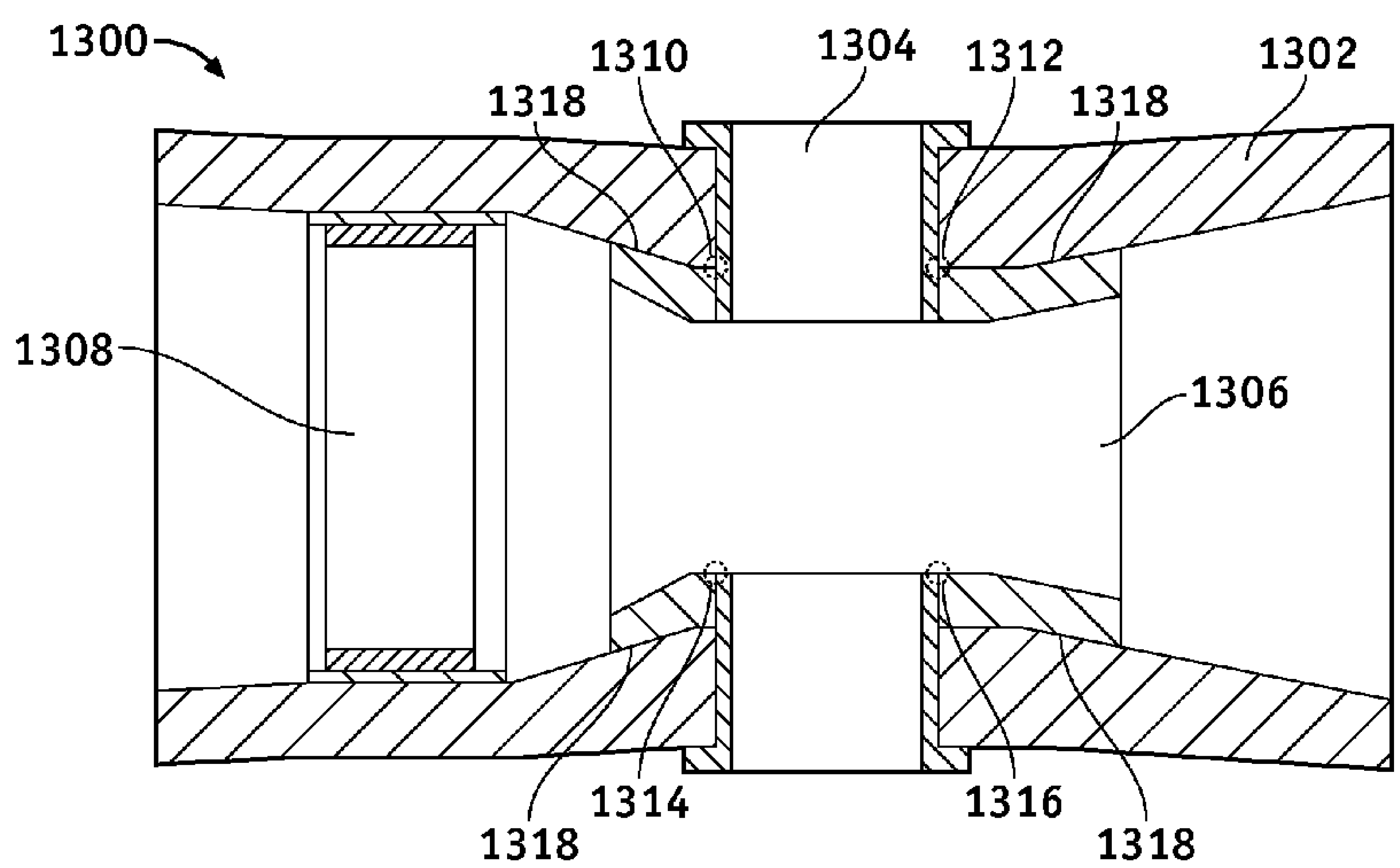

FIG. 13

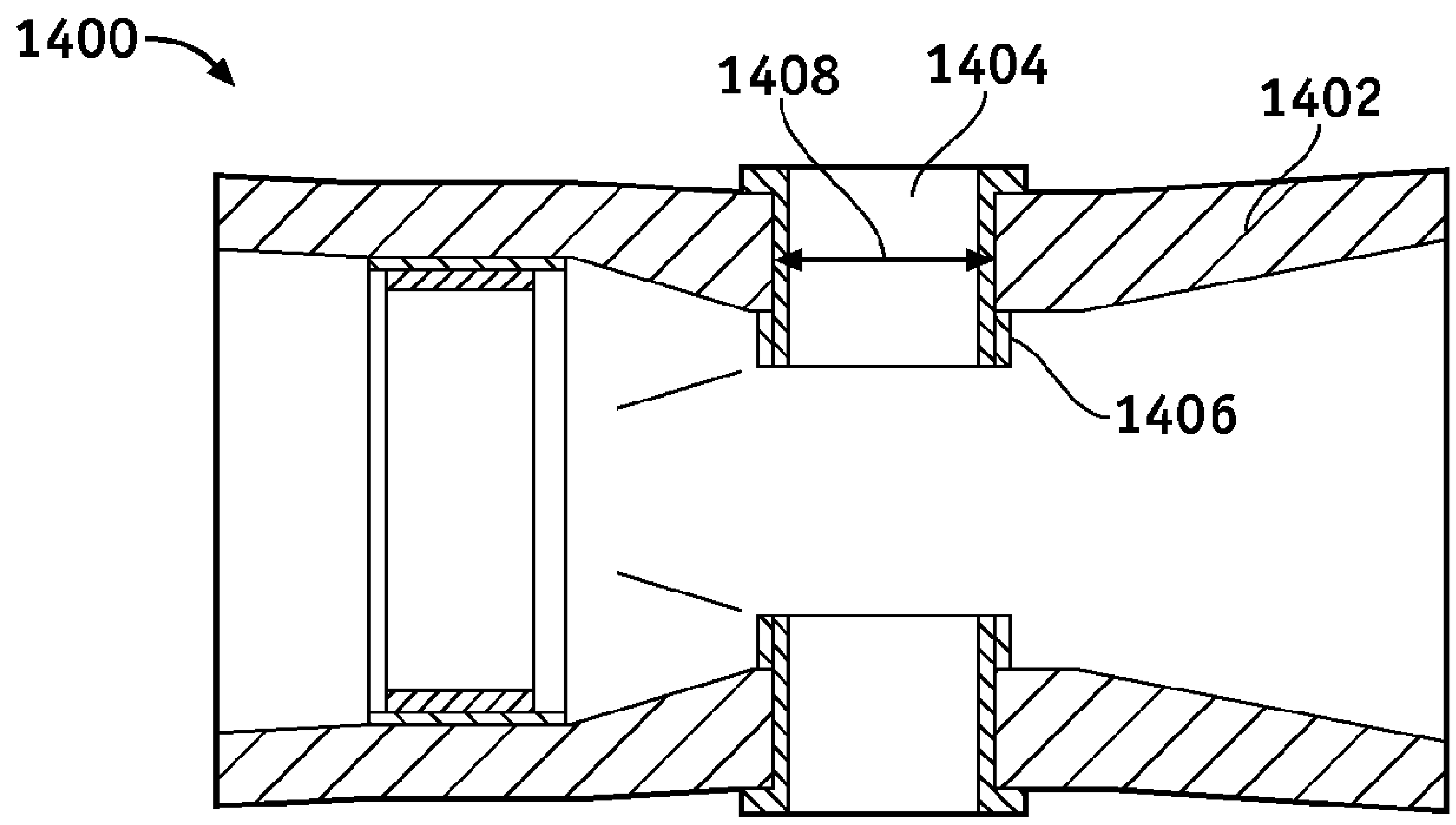

FIG. 14

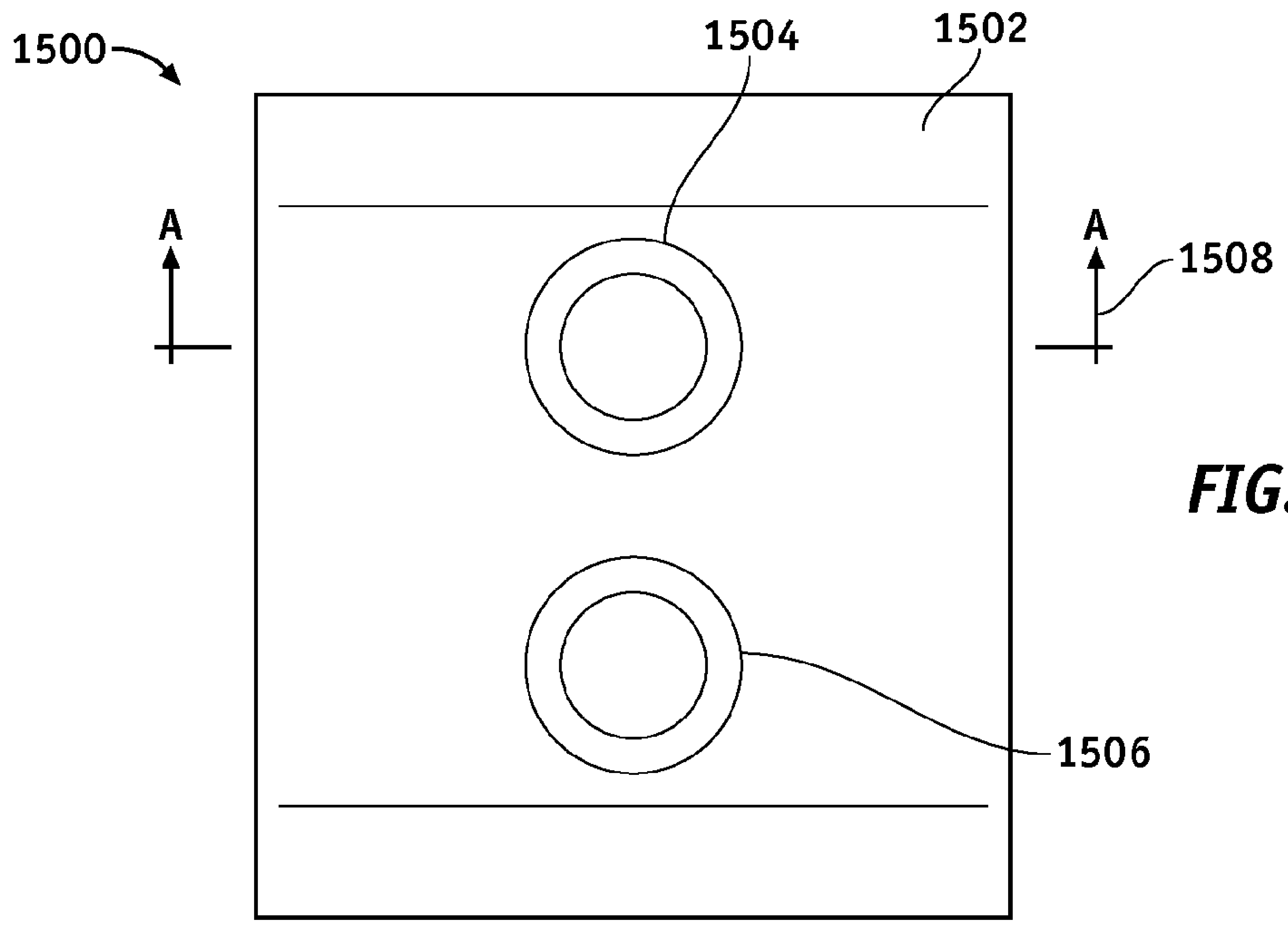

FIG. 15

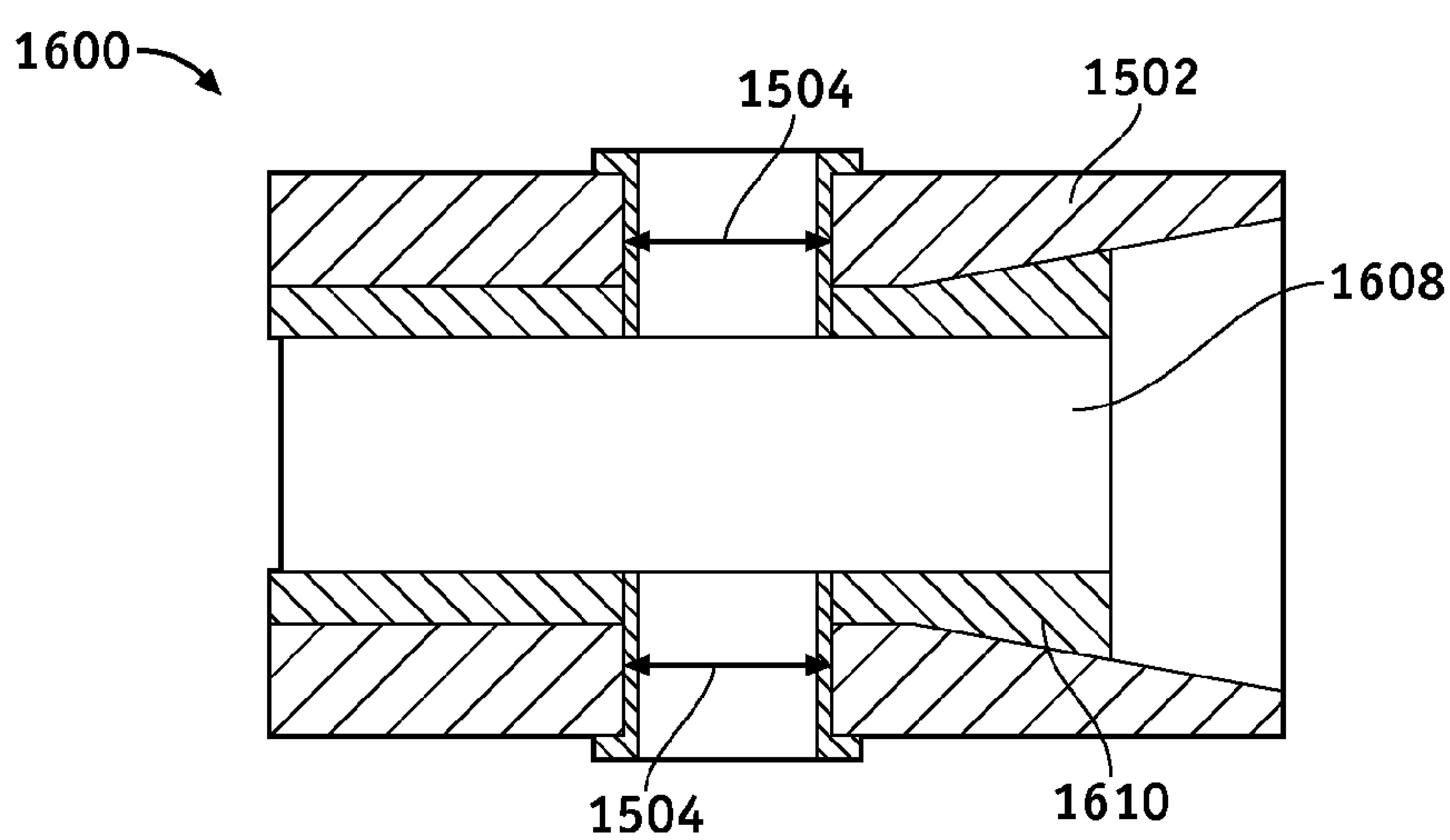

FIG. 16

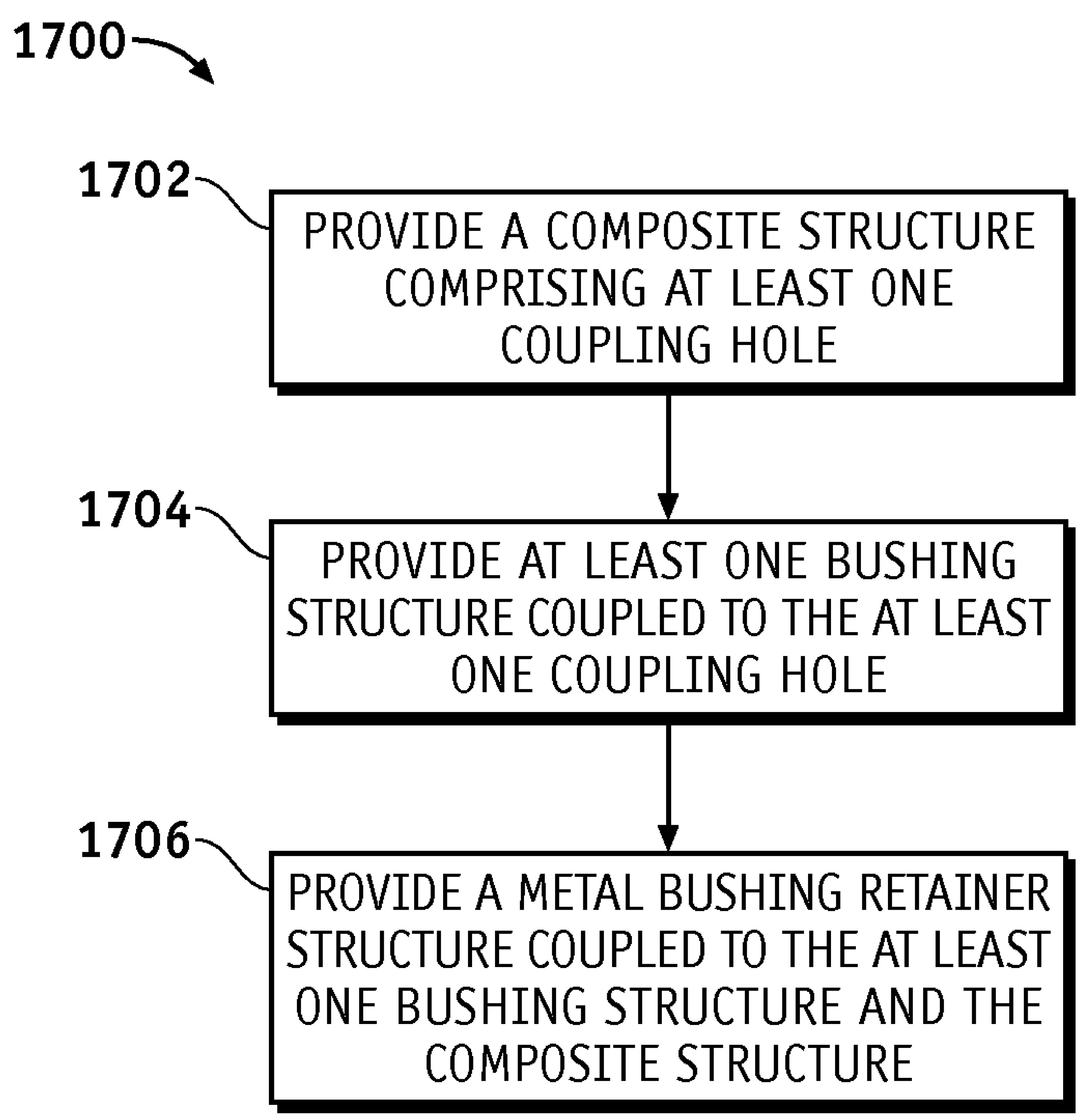
1700
1702
PROVIDE A COMPOSITE STRUCTURE COMPRISING AT LEAST ONE COUPLING HOLE
1704
PROVIDE AT LEAST ONE BUSHING STRUCTURE COUPLED TO THE AT LEAST ONE COUPLING HOLE
1706
PROVIDE A METAL BUSHING RETAINER STRUCTURE COUPLED TO THE AT LEAST ONE BUSHING STRUCTURE AND THE COMPOSITE STRUCTURE

FIG. 17

COMPOSITE BLADE ROOT-END DRILL-THROUGH LUG AND ATTACHMENT METHOD

GOVERNMENT RIGHTS

This invention was made with Government support under contract number, Phase II: W58RGZ-05-C-0410 with continuing development under current Phase III: W58RGZ-05-G-0005/0086 awarded by the U.S. Army. The government has certain rights in this invention.

FIELD

Embodiments of the present disclosure relate generally to material coupling. More particularly, embodiments of the present disclosure relate to reducing bearing stresses in composite materials.

BACKGROUND

In order to reduce weight and increase structural strength, aircraft designs increasingly utilize composite materials. While composite materials are generally strong under tensile, compression and bending loads, composite materials may have limited strength under bearing stresses. For example, helicopter blades attached to a rotor hub may experience bearing stresses at attachment points such as an attachment point of a helicopter blade to a rotor-hub strap pack.

Thus, there is a need for designs and methods for coupling objects made from composite materials to other objects while reducing bearing stresses.

SUMMARY

A method for reducing bearing stress in a composite structure is disclosed. The composite structure comprises at least one coupling hole for coupling the composite structure. A metal bushing retainer structure is coupled to the at least one coupling hole to absorb bearing stress and protect the at least one coupling hole from bearing stress. The metal bushing retainer structure allows the composite structure to be made substantially from composite material while being robust to coupling hole bearing stress.

In a first embodiment, an aircraft system comprises a rotor hub and a composite blade. The rotor hub comprises a blade connector, and the composite blade comprises a hub connector. The hub connector comprises a fastener assembly hole, a bushing coupled to the fastener assembly hole, and an inner metal bushing retainer coupled to the bushing and the fastener assembly hole. A fastener assembly couples the blade connector and the hub connector through the fastener assembly hole.

In a second embodiment, an apparatus reinforces a joint in a composite material. A composite structure comprises a fastener assembly hole, and a bushing structure is coupled to the composite structure. A first metal bushing retainer structure is coupled to the bushing structure and the composite structure.

In a third embodiment, a method reduces bearing stress in a composite structure. A composite structure comprising at least one coupling hole is provided. At least one bushing structure coupled to the at least one coupling hole is also provided. The method also provides a metal bushing retainer structure coupled to the at least one bushing structure and the composite structure.

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

BRIEF DESCRIPTION OF DRAWINGS

A more complete understanding of embodiments of the present disclosure may be derived by referring to the detailed description and claims when considered in conjunction with the following figures, wherein like reference numbers refer to similar elements throughout the figures. The figures are provided to facilitate understanding of the disclosure without limiting the breadth, scope, scale, or applicability of the disclosure. The drawings are not necessarily made to scale.

FIG. **1** is an illustration of a flow diagram of an exemplary aircraft production and service methodology.

FIG. **2** is an illustration of an exemplary block diagram of an aircraft.

FIG. **3** is an illustration of a top perspective and a side perspective view of an exemplary helicopter blade comprising a composite integrated root end cuff.

FIG. **4** is an illustration of an exemplary helicopter blade system comprising a helicopter blade and a rotor hub according to an embodiment of the disclosure.

FIG. **5** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure of a hub strap pack to a helicopter blade comprising according to an embodiment of the disclosure.

FIG. **6** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure showing deflection on a composite integrated root end cuff and inner metal bushing retainer according to an embodiment of the disclosure.

FIG. **7** is an illustration of an expanded view of the cross sectional view of the exemplary rotor blade-to-hub coupling structure **600** shown in FIG. **6** according to an embodiment of the disclosure.

FIG. **8** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure according to an embodiment of the disclosure.

FIG. **9** is an illustration of a cross sectional view taken along line B-B of the exemplary rotor blade-to-hub coupling structure of FIG. **8** according to an embodiment of the disclosure.

FIG. **10** is an illustration of a cross sectional view taken along line B-B of the exemplary rotor blade-to-hub coupling structure of FIG. **8** showing a separate external bushing retainer and an alternate geometry according to an embodiment of the disclosure.

FIG. **11** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure showing a fastener positioned in a metal inner bushing retainer according to an embodiment of the disclosure.

FIG. **12** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure showing combined pitch bearing and inner metal bushing retainer according to an embodiment of the disclosure.

FIG. **13** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure showing a pitch bearing separated from an inner metal bushing retainer according to an embodiment of the disclosure.

FIG. **14** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure showing simplified inner metal bushing retainers according to an embodiment of the disclosure.

FIG. **15** is an illustration of an exemplary rotor blade-to-hub coupling structure showing two parallel cold worked bushings according to an embodiment of the disclosure.

FIG. **16** is an illustration of a cross sectional view taken along line A-A of the exemplary rotor blade-to-hub coupling structure of FIG. **15**.

FIG. **17** is an illustration of a flow chart for an exemplary process for reducing bearing stress in a composite structure according to an embodiment of the disclosure.

DETAILED DESCRIPTION

The following detailed description is exemplary in nature and is not intended to limit the disclosure or the application and uses of the embodiments of the disclosure. Descriptions of specific devices, techniques, and applications are provided only as examples. Modifications to the examples described herein will be readily apparent to those of ordinary skill in the art, and the general principles defined herein may be applied to other examples and applications without departing from the spirit and scope of the disclosure. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description. The present disclosure should be accorded scope consistent with the claims, and not limited to the examples described and shown herein.

Embodiments of the disclosure may be described herein in terms of functional and/or logical block components and various processing steps. It should be appreciated that such block components may be realized by any number of hardware, software, and/or firmware components configured to perform the specified functions. For the sake of brevity, conventional techniques and components related to aircraft control systems, drilling and fastening techniques, high lift devices, blade design and assembly, composite manufacturing techniques such as prepreg and lamination, and other functional aspects of the systems (and the individual operating components of the systems) may not be described in detail herein. In addition, those skilled in the art will appreciate that embodiments of the present disclosure may be practiced in conjunction with a variety of different aircraft control systems, blade and hub configurations, and that the system described herein is merely one example embodiment of the disclosure.

Embodiments of the disclosure are described herein in the context of practical non-limiting applications, namely, helicopter blades. Embodiments of the disclosure, however, are not limited to such helicopter blade applications, and the techniques described herein may also be utilized in other composite material applications. For example, embodiments may be applicable to windmills, sports equipments, boats, automotive parts, marine applications, and the like.

As would be apparent to one of ordinary skill in the art after reading this description, the following are examples and embodiments of the disclosure are not limited to operating in accordance with these examples. Other embodiments may be utilized and structural changes may be made without departing from the scope of the exemplary embodiments of the present disclosure.

Referring more particularly to the drawings, embodiments of the disclosure may be described in the context of an aircraft manufacturing and service method **100** as shown in FIG. **1** and an aircraft **200** as shown in FIG. **2**. During pre-production, the exemplary method **100** may include specification and design **104** of the aircraft **200** and material procurement **106**. During production, component and subassembly manufacturing **108** and system integration **110** of the aircraft **200** takes place. Thereafter, the aircraft **200** may go through certification and delivery **112** in order to be placed in service **114**. While in service by a customer, the aircraft **200** is scheduled for routine maintenance and service **116** (which may also include modification, reconfiguration, refurbishment, and so on).

Each of the processes of method **100** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of venders, subcontractors, and suppliers; and an operator may be without limitation an airline, leasing company, military entity, service organization, and the like.

As shown in FIG. **2**, the aircraft **200** produced by the exemplary method **100** may include an airframe **218** with a plurality of systems **220** and an interior **222**. Examples of high-level systems **220** include one or more of a propulsion system **224**, an electrical system **226**, a hydraulic system **228**, an environmental system **230**, and a rotor system **232**. Any number of other systems may also be included. Although an aerospace example is shown, the embodiments of the disclosure may be applied to other industries, such as the automotive, windmills, sports equipments, boats, marine applications, and the like.

Apparatus and methods embodied herein may be employed during any one or more of the stages of the production and service method **100**. For example, components or subassemblies corresponding to production process **108** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft **200** is in service. In addition, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during the production stages **108** and **110**, for example, by substantially expediting assembly of or reducing the cost of an aircraft **200**. Similarly, one or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft **200** is in service, for example and without limitation, to maintenance and service **116**.

FIG. **3** is an illustration of a top and a side view of an exemplary composite blade **300** comprising a composite integrated root end cuff **304** according to an embodiment of the disclosure. The exemplary composite blade **300** comprises a composite airfoil **302**, the composite integrated root end cuff **304**, a fastener assembly hole **306**, and a pitch control device **308**.

The composite airfoil **302** may comprise a composite blade spar **310** continuously coupled to the composite integrated root end cuff **304**. The composite airfoil **302** is weight efficient, less susceptible to fatigue, and has a lower and more uniform stiffness than a metal airfoil, which reduces stress concentration that may occur in a metal airfoil.

The composite blade spar **310** provides structural support to the composite airfoil **302** and the composite integrated root end cuff **304** of the composite blade spar **310**, and provides a coupling mechanism to a rotor hub (**412** in FIG. **4**).

The fastener assembly hole **306** may be created by drilling through the thickened section **312** in the composite blade spar **310**, and may be re-enforced with metallic cold work expansion bushings **314** as explained in more detail in the context of discussion of FIG. **5** below. Width **316** of the thickened section **312** may vary depending on design requirements. The width **316** of the thickened section may be, for example but without limitation, about 2 inches to about 18 inches, or the like.

Composite laminate may be thickened locally at the fastener assembly hole **306**, by, for example but without limitation, inclusion of additional plies into the composite laminate, and the like. If the composite laminate is constructed using braiding manufacturing technology, then a fastener region such as the thickened section **312** near the fastener assembly hole **306** may be thickened. The thickening may be accomplished by, for example but without limitation: a) inclusion of additional dry fabric forms between successive braided layers of the composite laminate; b) varying a ply angle within each braided layer of the composite laminate; and by a combination of (a) and (b), or the like.

A drill-through approach provides for a continuous composite structure eliminating structural bonding and mechanical joints between distinct separate functioning blade sections such as the composite integrated root end cuff **304** to the composite blade spar **310**. The drill-through composite solution performs load carrying functions, while achieving a lower section stiffness, reduced weight, machining and assembly cost goals. Fatigue life benefits of composite materials are realized throughout the composite blade **300** by providing a continuous unitary composite structure that eliminates the mechanical or structural bonding of two otherwise distinct sections to complete a blade assembly, where one section is made of metal. Weight can be reduced by replacing a metallic root fitting component with a continuous composite section, since composites offer a significantly lower density and a high strength to weight ratio. The drill-through approach provides a structurally efficient coupling mechanism for coupling the composite blade **300** to a rotor hub (**412** in FIG. **4**) at the composite integrated root end cuff **304** as explained in more detail in the context of discussion of FIG. **4** below.

The pitch control device **308** may be coupled to a pitch linkage assembly (not shown) to provide a pitch control mechanism for the composite airfoil **302**.

FIG. **4** is an illustration of an exemplary helicopter blade system **400** comprising a helicopter composite rotor blade **402** comprising a hub connector **438** and a rotor hub **412** comprising a blade connector **418**. The helicopter composite rotor blade **402** comprises the composite airfoil **302**, the composite integrated root end cuff **304**, the fastener assembly hole **306** coupled to a fastener assembly **430** in the hub connector **438**, and the pitch control device **308**. The exemplary helicopter blade system **400** has a structure similar the exemplary composite blade **300**; therefore, common features, functions, and elements may not be redundantly described here. The fastener assembly **430** couples the blade connector **418** to the hub connector **438** through the fastener assembly hole **306** as explained in more detail below. The hub connector **438** is suitably assembled to reduce composite bearing stresses in the fastener assembly hole **306** as explained in more detail below.

The rotor hub **412** comprises a hub strap pack **414**, a hub section **416**, and the blade connector **418**. The rotor hub **412** is coupled to the helicopter composite rotor blade **402** via the blade connector **418**. The rotor hub **412** rotates about axes **420** and rotates the helicopter composite rotor blade **402** along therewith to generate thrust. In operation, the helicopter composite rotor blade **402** generates a centrifugal force **436** as it rotates which causes a root end cuff reaction force **422** and thereby a hub reaction force **424**. The hub reaction force **424** may be, for example but without limitation, about 10,000 lbs to about 150,000 lbs, and the like. The hub reaction force **424** may cause composite bearing stresses in the fastener assembly hole **306**. Embodiments of the disclosure reduce or redistribute these composite bearing stresses as explained in more detail below. Arrow **440** indicates a direction of rotation of the helicopter composite rotor blade **402** about the axis **420**.

The hub strap pack **414** absorbs the hub reaction force **424** due to action of the centrifugal force **436** from the helicopter composite rotor blade **402**.

The hub section **416** provides a reaction for chord-wise and flap-wise bending moments, supports the hub strap pack **414**, and fits into the composite integrated root end cuff **304**.

The blade connector **418** couples the helicopter composite rotor blade **402** to the rotor hub **412** by coupling the blade connector **418** to the fastener assembly hole **306** via a fastener assembly (**506** in FIG. **5**). In this manner, the centrifugal force **436** caused by rotation of the helicopter composite rotor blade **402** is transferred from the composite integrated root end cuff **304** to the rotor hub **412**. The blade connector **418** is fitted to align with the fastener assembly hole **306**.

FIG. **5** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure **500** (hub connector **500** similar to hub connector **438** in FIG. **4**) of a strap pack **504** to the helicopter composite rotor blade **402** (FIG. **4**) according to an embodiment of the disclosure. The exemplary rotor blade-to-hub coupling structure **500** comprises a composite integrated root end cuff **502**, the strap pack **504**, a fastener assembly **506**, a cold worked bushing **508**, an inner metal bushing retainer **510**, and a fastener assembly hole **512**. The cold worked bushing **508** is coupled to the fastener assembly hole **512**, and the inner metal bushing retainer **510** is coupled to the cold worked bushing **508** and the fastener assembly hole **512**. In this manner, the bearing stresses in the fastener assembly hole **512/306** are reduced as explained in more detail below.

The composite integrated root end cuff **502** (composite structure; **304** in FIGS. **3-4**) comprises an integrated composite structure comprising the fastener assembly hole **512**.

The strap pack **504** is operable to absorb the hub reaction force **424** (FIG. **4**) due to action of the centrifugal force **436** from the helicopter composite rotor blade **402** via the composite integrated root end cuff **502**. A hub section **514** may cover the strap pack **504**.

The fastener assembly **506** fits through the fastener assembly hole **512** to couple the composite integrated root end cuff **502** to the strap pack **504**. The fastener assembly **506** may be, for example but without limitation, a preload clamping bushing as shown in FIG. **5**, a pin-type joint **516**, a bushing **518**, a lug bolt **520**, a lug bolt assembly **522**, an axle **524**, a cotter pin **526**, and the like.

The cold worked bushing **508** (bushing structure) is installed in the fastener assembly hole **512** between the composite integrated root end cuff **502** and the fastener assembly **506**, and may be coupled to the composite integrated root end cuff **502**. The cold worked bushing **508** is coupled or attached to the metal bushing retainer **510** to reinforce the composite integrated root end cuff **502** against bearing stresses. For example but without limitation, the cold worked bushing **508** may be attached to the metal bushing retainer **510** via cold working, diffusion bonding, super plastic diffusion bonding, welding, soldering, and the like. The cold worked bushing **508** provides good uniform load transfer of bearing stress, thereby protecting the composite integrated root end cuff **502** from bearing stresses caused by forces from interaction of the composite integrated root end cuff **502** with the fastener assembly **506**. The embodiment in FIG. **5** shows paired bushings as an example of the cold worked bushing **508**, however other bushing configurations, such as but without limitation, a single bushing through a flat surface, multiple bushings through multiple holes in a surface, and the like, may also be used. The cold worked bushing **508** may comprise, for example but without limitation, metallic cold work expansion bushings, and the like.

The inner metal bushing retainer **510** (metal bushing retainer) reinforces and protects the composite integrated root end cuff **502** from bearing stresses that may be caused by forces from interaction of the composite integrated root end cuff **502** with the fastener assembly **506**. These forces may be caused by, for example, the hub reaction force **424** within the fastener assembly **506** due to the centrifugal force **436**. The inner metal bushing retainer **510** may be configured to incorporate and perform other functions, such as providing pitch bearing and flap and chord load reaction point support. The inner metal bushing retainer **510** may be coupled or attached to the composite integrated root end cuff **502** via, for example but without limitation, adhesive bonding, co-curing, gluing, and the like.

The above description and the description below refer to elements or nodes or features being "attached" together. As used herein, unless expressly stated otherwise, "attached" means that one element/node/feature is directly mechanically joined or fused to another element/node/feature. For example, an element may be attached to another element by, for example but without limitation, cold working, diffusion bonding, super plastic diffusion bonding, welding, soldering, riveting, co-curing, pressure forming, adhesive bonding, gluing, and the like.

FIG. **6** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure **600** showing deflection on a composite integrated root end cuff **602** and an inner metal bushing retainer **610** according to an embodiment of the disclosure. The exemplary rotor blade-to-hub coupling structure **600** comprises the composite integrated root end cuff **602**, a strap pack **604**, a fastener assembly **606**, a cold worked bushing **608**, and the inner metal bushing retainer **610**.

The composite integrated root end cuff **602** is pulled by centrifugal force **612** (**436** in FIG. **4**) from the helicopter composite rotor blade **402** (FIG. **4**) when rotating in an outward direction **614** away from the rotor hub **412** (FIG. **4**).

The strap pack **604** is stretched by the centrifugal force **612** from the composite integrated root end cuff **602** away from the rotor hub **412**, and by a centripetal force **616** from the rotor hub **412** in an inward direction **618** toward the rotor hub **412**.

The fastener assembly **606** (**506** in FIG. **5**) couples the composite integrated root end cuff **602** to the strap pack **604**, and may be stressed by their opposing centrifugal force **612** and the centripetal force **616**.

The cold worked bushing **608** (**314** in FIGS. **3** and **508** in FIG. **5**) protects the composite integrated root end cuff **602** from bearing stresses at edges **620/622/624/626**.

The inner metal bushing retainer **610** may be coupled or attached to the cold worked bushing **608**. Peak contact stress in the composite integrated root end cuff **602** is reduced due to loads such as the centrifugal force **612** being redirected by the inner metal bushing retainer **610**, thereby protecting the composite integrated root end cuff **602** from bearing stresses at the edges **620/622/624/626** as explained below.

FIG. **7** is an illustration of an expanded view of the cross sectional view of the exemplary rotor blade-to-hub coupling structure **600** according to an embodiment of the disclosure. The inner metal bushing retainer **610** dissipates bearing stresses at edges **624/626** from the fastener assembly **606** into an interface or contact area **722/724** of the inner metal bushing retainer **610** with the composite integrated root end cuff **602** to protect the edges **626/624**. For example, a moment **704** created by bending in the fastener assembly **606** is partially reacted by the inner metal bushing retainer **610**. The moment **704** is reacted by distributed load **706** of a large contact area such as the contact area **722**, thereby reducing bearing stress at edge **624**. In addition, the inner metal bushing retainer **610** reinforces the composite integrated root end cuff **602**. The inner metal bushing retainer **610** may be made in any shape suitable to protect the composite integrated root end cuff **602** from bearing stresses at the edges **620/622/624/626**. The inner metal bushing retainer **610** may, for example and without limitation, flare laterally outwardly from a conic taper section **632** at or near an inner section **708** to increased cross sections **628/630** at its both ends **710/712** respectively with a generally, for example but without limitation, a parabolic external profile, and the like. Cross sectional dimensions of the conic taper section **632**, the cross section **628**, and the cross section **630** may be, for example but without limitation, about 1.5 inches to about 2.25 inches, about 1.6 inches to about 2.5 inches, about 1.2 inches to about 2.0 inches respectively, and the like.

In one embodiment, a tapered outer section **714** may be used to provide a means for load sharing between the inner metal bushing retainer **610** and the composite integrated root end cuff **602**. Without the tapered outer section **714**, the centripetal force **616** may be transferred directly to the fastener assembly **606** causing additional bearing stresses on the edges **620/622/624/626** due to bending of the fastener assembly **606**. The inner metal bushing retainer **610** may be made of any metal such as but without limitation, titanium, steel, aluminum, and the like, depending, for example but without limitation, on a type of the composite used for making the composite integrated root end cuff **602** and the composite blade spar **310**, and the like.

FIG. **8** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure **800** according to an embodiment of the disclosure. The exemplary rotor blade-to-hub coupling structure **800** comprises a composite integrated root end cuff **802**, and a composite bushing section **804**. Embodiments shown in FIG. **8** may have functions, material, and structures that are similar to the embodiments shown in FIGS. **3-7**. Therefore common features, functions, and elements may not be redundantly described here.

The composite integrated root end cuff **802** may be coupled to the hub section **416** (FIG. **4**) by pitch bearings **806**. The pitch bearings **806** allow the composite integrated root end cuff **802** and thus the helicopter composite rotor blade **808** (**402** in FIG. **4**) to change pitch. During maintenance parts of the pitch bearings **806** may be separately replaced.

The composite bushing section **804** is located at a thickened composite section **810** and comprises cold worked bushings **812**, and an inner metal bushing retainer **814**. Various geometries or configurations of the composite bushing section **804** may be used as explained in more detail below.

FIG. **9** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure **900** taken along a line B-B **816** of the composite bushing section **804** of the exemplary rotor blade-to-hub coupling structure **800** according to an embodiment of the disclosure. The exemplary rotor blade-to-hub coupling structure **900** comprises a composite integrated root end cuff **902**, a cold worked bushing **904**, and an inner metal bushing retainer **906**.

The composite integrated root end cuff **902** and the inner metal bushing retainer **906** comprise a square box shaped cross section. A width **908** of the composite integrated root end cuff **902** substantially perpendicular to the fastener assembly hole **306** may be, for example but without limitation, about 2.5 to about 4.5 inches, and the like. A width **910** of the composite integrated root end cuff **902** substantially parallel to the fastener assembly hole **306** may be, for example but without limitation, about 2.5 inches to about 4.5 inches, and the like. A material thickness **912** of the composite integrated root end cuff **902** may be, for example but without limitation, about 0.2 inches to about 0.8 inches, and the like.

FIG. **10** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure **1000** taken along the line B-B **816** of the composite bushing section **804** of the exemplary rotor blade-to-hub coupling **800** showing an exemplary separate external metal bushing retainer **1008** and an alternate geometry according to an embodiment of the disclosure. The exemplary rotor blade-to-hub coupling structure **1000** comprises a composite integrated root end cuff **1002**, a cold worked bushing **1004**, an inner metal bushing retainer **1006**, and the external metal bushing retainer **1008**.

The exemplary rotor blade-to-hub coupling structure **1000** comprises both the inner metal bushing retainer **1006** and the external metal bushing retainer **1008**. The external metal bushing retainer **1008** is coupled to the cold worked bushing **1004** and may be attached thereto.

The cold worked bushing **1004** may be, for example but without limitation, circular, an annulus, tubular, and the like. The inner metal bushing retainer **1006** and the external metal bushing retainer **1008** reduce bearing stresses in the composite integrated root end cuff **1002** by redistributing the bearing stresses in the fastener assembly **506**. The bearing stresses are redistributed from blade loads into the adjacent composite faces by the inner metal bushing retainer **1006** and the external metal bushing retainer **1008**. The redistribution of bearing stresses increases a load carrying capability and life of the composite integrated root end cuff **1002**. A material thickness **1010** of the composite integrated root end cuff **1002** may be, for example but without limitation, about 0.16 inches to about 3 inches, and the like. A diameter **1012** of the composite integrated root end cuff **1002** may be, for example and without limitation, about 2 inches to about 8 inches.

FIG. **11** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure **1100** showing a fastener assembly **1108** positioned in an inner metal bushing retainer **1106** according to an embodiment of the disclosure. The exemplary rotor blade-to-hub coupling structure **1100** comprises an composite integrated root end cuff **1102**, a cold worked bushing **1104**, the inner metal bushing retainer **1106**, and the fastener assembly **1108** is in the inner metal bushing retainer **1106** with the cold worked bushing **1104** therebetween.

FIG. **12** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure **1200** showing a combined pitch bearing **1208** and an inner metal bushing retainer **1206** according to an embodiment of the disclosure. The exemplary rotor blade-to-hub coupling structure **1200** comprises a composite integrated root end cuff **1202**, a cold worked bushing **1204**, and the inner metal bushing retainer **1206**. The inner metal bushing retainer **1206** comprises the pitch bearing **1208**. Combining the inner metal bushing retainer **1206** and the pitch bearing **1208** may lower a cost by combining two devices into one. In one embodiment, a tapered outer section **1210** feature can be incorporate into the inner metal bushing retainer **1206** to provide further reduction in the composite section bearing stress in the composite integrated root end cuff **1202**. The tapered outer section **1210** provides a means for load sharing between the inner metal bushing retainer **1206** (**610** in FIG. **6**) and the composite integrated root end cuff **1202** (**602** in FIG. **6**), thereby reducing the bearing stresses at the edges **620**/**622**/**624**/**626**. As shown in FIG. **12**, the inner metal bushing retainer **1206** extends to the tapered outer section **1210** and supports the pitch bearing **1208**.

FIG. **13** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure **1300** showing a pitch bearing **1308** separated from an inner metal bushing retainer **1306** according to an embodiment of the disclosure. The exemplary rotor blade-to-hub coupling structure **1300** comprises a composite integrated root end cuff **1302**, a cold worked bushing **1304**, the inner metal bushing retainer **1306**, and the pitch bearing **1308**. In comparison to the exemplary rotor blade-to-hub coupling structure **1200**, the exemplary rotor blade-to-hub coupling structure **1300** comprises the inner metal bushing retainer **1306** separated from the pitch bearing **1308**. The inner metal bushing retainer **1306** may be cold worked with the composite integrated root end cuff **1302**. The rotor blade-to-hub coupling structure **1300** allows redistribution of a stress or stresses caused by the fastener assembly **606** across interface surfaces **1318** of the composite integrated root end cuff **1302** and the composite integrated root end cuff **1302** rather than the edges **1310**/**1312**/**1314**/**1316**.

FIG. **14** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure **1400** showing a simplified inner metal bushing retainer **1406** according to an embodiment of the disclosure. The exemplary rotor blade-to-hub coupling structure **1400** comprises a composite integrated root end cuff **1402**, a cold worked bushing **1404**, the inner metal bushing retainer **1406**, and a fastener assembly hole **1408**. The inner metal bushing retainer **1406** comprises a simple local retainer. The inner metal bushing retainer **1406** may be installed during installation of the cold worked bushing **1404**. The inner metal bushing retainer **1406** may be slid over the cold worked bushing **1404** and secured in place by expanding the cold worked bushing **1404**. The cold worked bushing **1404** is positioned in the fastener assembly hole **1408** and through the inner metal bushing retainer **1406**. The cold worked bushing **1404** may be coupled or attached to the inner metal bushing retainer **1406** to reinforce the fastener assembly hole **1408**.

FIG. **15** is an illustration of an exemplary rotor blade-to-hub coupling structure **1500** showing two parallel cold worked bushings according to an embodiment of the disclosure. The exemplary rotor blade-to-hub coupling structure **1500** comprises a composite integrated root end cuff **1502**, a first fastener assembly hole **1504**, and a second fastener assembly hole **1506**. The exemplary rotor blade-to-hub coupling structure **1500** may comprise various numbers of holes, for example but without limitation, two, and the like. The first fastener assembly hole **1504** and the second fastener assembly hole **1506** are operable to provide a distributed loading through two fastener assemblies (not shown).

FIG. **16** is an illustration of a cross sectional view of an exemplary rotor blade-to-hub coupling structure **1600** taken along a line A-A **1508** of the exemplary rotor blade-to-hub coupling structure **1500**. The exemplary rotor blade-to-hub coupling structure **1600** comprises the composite integrated root end cuff **1502**, the first fastener assembly hole **1504**, and an inner metal bushing retainer **1608**. The first fastener assembly hole **1504** and the second fastener assembly hole **1506** are coupled or attached in common to the inner metal bushing retainer **1608**. The inner metal bushing retainer **1608** may comprise a tapered outer section **1610** widened to accommodate two or more fastener assemblies. In this case, two parallel fastener assemblies (not shown) may be fitted into the first fastener assembly hole **1504** and the second fastener assembly hole **1506** to absorb blade loads on the composite blade **300/402**, such as but without limitation, centrifugal force, flap and chord bending and torsion moments.

FIG. **17** is an illustration of a flow chart for an exemplary process for reducing bearing stress in a composite structure according to an embodiment of the disclosure. The various tasks performed in connection with process **1700** may be performed by software, hardware, firmware, or any combination thereof. For illustrative purposes, the following description of process **1700** may refer to elements mentioned above in connection with FIGS. **1-16** and. In practical embodiments, portions of process **1700** may be performed by different elements of exemplary rotor blade-to-hub coupling structures **300-1600** such as the composite integrated root end cuff **502**, the strap pack **504**, the fastener assembly **506**, the cold worked bushing **508**, the inner metal bushing retainer **510**, and the like. Process **1700** may have functions, material, and structures that are similar to the embodiments shown in FIGS. **1-16**. Therefore common features, functions, and elements may not be redundantly described here.

Process **1700** may begin by providing a composite structure, such as but without limitation, the composite blade **300** comprising a coupling hole such as the fastener assembly hole **306/512** (task **1702**). The fastener assembly hole **306/512** may be drilled through the composite blade **300** during or after making the composite blade **300**. The composite integrated end root cuff **304** of the composite blade **300** may have a thickness larger in comparison to a composite airfoil **302** of the composite blade **300**. In addition, the thickened section **312** in the composite blade spar **310** may have a thickness larger in comparison to the composite airfoil **302** of the composite blade **300**.

Process **1700** may continue by providing a bushing structure such as the cold work bushing **508** coupled to the fastener assembly hole **306/512** (task **1704**). Expanding the cold work bushing **508** may function to compression form the cold work bushing **508** into a strong fit with the fastener assembly hole **306/512**.

Process **1700** may continue by providing a metal bushing retainer structure such as the inner metal bushing retainer **510** coupled or attached to the bushing structure such as the cold work bushing **508** and the fastener assembly hole **306/512** (task **1706**). The metal bushing retainer structure may be coupled or attached to a composite structure such as the composite blade **300**, as explained in the context of discussion of FIG. **5** above. In particular, the metal bushing retainer structure may be coupled or attached to the thickened section **312**.

In this way, various embodiments of the disclosure provide for coupling of composite materials to other objects via a coupling hole while reducing bearing stresses in the composite materials around the coupling hole. In addition, various embodiments of the disclosure provide for substantially unitary composite parts to be used in more applications. Relative to metal-composite hybrids, unitary composite parts utilizing various embodiments of the disclosure provide an optimized stiffness, higher fatigue life, lower material weight and manufacturing cost, allows simple field inspection methods (visual) and a benign (slow propagating) readily inspectable failure mode. Furthermore, various embodiments minimize a need for detailed composite prepreg kitting, human assembly, and minimizes manufacturing process steps. Thereby, automated robust process methods may be used that to reduce cost and produce a high production yield.

While at least one example embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the example embodiment or embodiments described herein are not intended to limit the scope, applicability, or configuration of the subject matter in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the described embodiment or embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope defined by the claims, which includes known equivalents and foreseeable equivalents at the time of filing this patent application.

The above description refers to elements or nodes or features being "connected" or "coupled" together. As used herein, unless expressly stated otherwise, "connected" means that one element/node/feature is directly joined to (or directly communicates with) another element/node/feature, and not necessarily mechanically. Likewise, unless expressly stated otherwise, "coupled" means that one element/node/feature is directly or indirectly joined to (or directly or indirectly communicates with) another element/node/feature, and not necessarily mechanically. Thus, although FIGS. **3-16** depict example arrangements of elements, additional intervening elements, devices, features, or components may be present in an embodiment of the disclosure.

Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing: the term "including" should be read as mean "including, without limitation" or the like; the term "example" is used to provide exemplary instances of the item in discussion, not an exhaustive or limiting list thereof; and adjectives such as "conventional," "traditional," "normal," "standard," "known" and terms of similar meaning should not be construed as limiting the item described to a given time period or to an item available as of a given time, but instead should be read to encompass conventional, traditional, normal, or standard technologies that may be available or known now or at any time in the future. Likewise, a group of items linked with the conjunction "and" should not be read as requiring that each and every one of those items be present in the grouping, but rather should be read as "and/or" unless expressly stated otherwise. Similarly, a group of items linked with the conjunction "or" should not be read as requiring mutual exclusivity among that group, but rather should also be read as "and/or" unless expressly stated otherwise. Furthermore, although items, elements or components of the disclosure may be described or claimed in the singular, the plural is contemplated to be within the scope thereof unless limitation to the singular is explicitly stated. The presence of broadening words and phrases such as "one or more," "at least," "but not limited to" or other like phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent.

The invention claimed is:

1. An aircraft system comprising:

a rotor hub comprising a blade connector;

a composite blade comprising a hub connector comprising:

a composite integrated root end cuff comprising a fastener assembly hole;

a bushing coupled to the fastener assembly hole; and

an inner metal bushing retainer coupled to the bushing and the fastener assembly hole, the bushing mechanically fused to the inner metal bushing retainer; and

a fastener assembly coupled to the blade connector and the hub connector through the fastener assembly hole.

2. The aircraft system according to claim **1**, wherein the bushing is mechanically fused to the inner metal bushing retainer by cold work expansion of the bushing.

3. The aircraft system according to claim **1**, further comprising an external metal bushing retainer coupled to the bushing.

4. The aircraft system according to claim **3**, wherein the external metal retainer is attached to the bushing.

5. The aircraft system according to claim **1**, wherein the inner metal bushing retainer is coupled to a pitch bearing.

6. The aircraft system according to claim **1**, wherein the inner metal bushing retainer comprises a tapered section operable to provide load sharing between the inner metal bushing retainer and the composite integrated root end cuff.

7. The aircraft system according to claim **1**, wherein the composite blade further comprises a composite root end.

8. The aircraft system according to claim **7**, wherein the inner metal bushing retainer is mechanically fused to the composite root end.

9. The aircraft system according to claim **7**, wherein the composite root end is thickened near the fastener assembly hole.

10. The aircraft system according to claim **7**, wherein the composite root end is integral with a blade spar.

11. The aircraft system according to claim **1**, wherein:
- the composite blade comprises at least two fastener assembly holes; and
- at least one inner metal bushing retainer is coupled to the at least two fastener assembly holes.

12. The aircraft system according to claim **1**, wherein the fastener assembly comprises one of the group consisting of: a preload clamping bushing, a pin-type joint, a bushing, a lug bolt, a lug bolt assembly, an axle, and a cotter pin.

13. An apparatus for reinforcing a joint in a composite material, the apparatus comprising:
- a composite structure comprising a composite integrated root end cuff comprising a fastener assembly hole;
- a bushing structure coupled to the composite structure; and
- a first metal bushing retainer structure coupled to the bushing structure, and the composite structure, the bushing structure mechanically fused to the first metal bushing retainer structure.

14. The apparatus according to claim **13**, wherein the first metal bushing retainer structure is attached to the composite structure.

15. The apparatus according to claim **13**, wherein the bushing structure comprises a tapered section operable to provide load sharing between the first metal bushing retainer structure and the composite structure.

16. The apparatus according to claim **13**, further comprising a second metal bushing retainer structure coupled to the bushing structure.

17. The apparatus according to claim **16**, wherein the second metal bushing retainer structure is attached to the bushing structure.

18. A method for reducing bearing stress in a composite structure, the method comprising:
- providing a composite structure comprising at least one coupling hole;
- providing at least one bushing structure coupled to the at least one coupling hole; and
- providing a metal bushing retainer structure coupled to the at least one bushing structure and the composite structure, the at least one bushing structure coupled to the metal bushing retainer structure by expanding the at least one bushing structure.

19. The method according to claim **18**, further comprising: providing coupling means coupled to the at least one bushing structure and the metal bushing retainer structure.

20. The method according to claim **18**, further comprising: providing a rotor hub comprising a connector coupled to the composite structure through the at least one coupling hole via coupling means.

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